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# Use of the target diagnostic control system in the National Ignition Facility

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The extreme physics of targets shocked by NIF's 192-beam laser are observed by a diverse suite of diagnostics including optical backscatter, time-integrated, time resolved and gated X-ray sensors, laser velocity interferometry, and neutron time of flight. Diagnostics to diagnose fusion ignition implosion and neutron emissions have been developed. A Diagnostic Control System (DCS) for both hardware and software facilitates development and eases integration. Each complex diagnostic typically uses an ensemble of electronic instruments attached to sensors, digitizers, cameras, and other devices. In the DCS architecture each instrument is interfaced to a low-cost Window XP processor and Java application. Instruments are aggregated as needed in the supervisory system to form an integrated diagnostic. The Java framework provides data management, control services and operator GUI generation. During the past several years, over thirty-six diagnostics have been deployed using this architecture in support of the National Ignition Campaign (NIC). The DCS architecture facilitates the expected additions and upgrades to diagnostics as more experiments are performed. This paper presents the DCS architecture, framework and our experiences in using it during the NIC to operate, upgrade and maintain a large set of diagnostic instruments.

Keywords: National Ignition Facility; Control System; Data Acquisition

## 1. Introduction

### 1.1 NIF Target Diagnostics

The physics requirements derived from The National Ignition Facility (NIF)[1] experimental campaigns are leading to a wide variety of target diagnostics along with differing diagnostic configurations for each experiment. To better understand physics issues in energetics, laser-hohlraum interaction, hydrodynamics, and equation of state of materials, over 36 diagnostics containing over 300 data channels were developed and deployed for the NIF energetic experiments from 2009 to 2011. Each diagnostic has unique controls and data acquisition requirements. Optical diagnostics observe backscattered light from targets and provide insight to energy conversion. A velocity interferometer measures the laser-shocked target surfaces. X-ray diagnostics can be integrating, time resolved, or gated to capture a snapshot of the target during laser-driven shock. Neutron time of flight, spectroscopy, and neutron imaging observe ignition experiments. Table 1 lists target diagnostics currently commissioned for NIF and Figure 1 shows optical, X-ray, and neutron diagnostics on the chamber.

### 1.2 NIF Control System

The NIF computer control system is comprised of several different systems that are implemented using appropriate technologies. The Safety Interlock System (SIS) assures that personnel are safe during system operations. The Industrial Control System (ICS) controls facility utilities such as vacuum, gas, and cooling systems. The access control system (ACS) controls and audits personnel traffic throughout the NIF facility. These three systems are implemented using

commercially available programmable logic controllers. The Laser and diagnostics are controlled by a much larger Integrated Computer Control System (ICCS)[2]. This system incorporates over 1,000 front-end processors, servers and operator workstations used to control and monitor the laser as well as to integrate the suite of target diagnostics that are the focus of this paper.

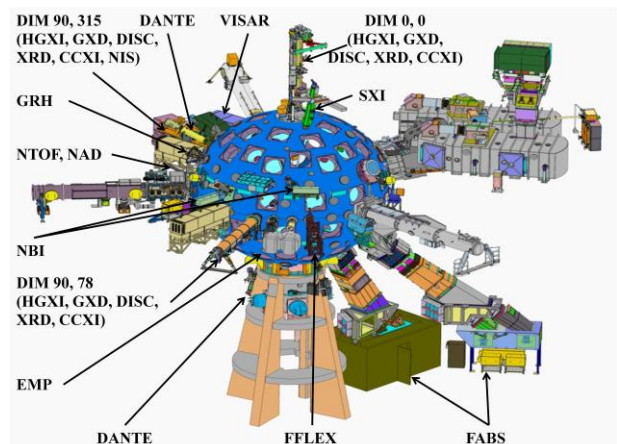


Fig.1 Optical, X-ray, and neutron target diagnostics are deployed on the NIF target chamber

### 1.3 Target Diagnostic Control System

Target diagnostic controls are incorporated as part of the ICCS architecture. Diagnostics originate from other US laboratories, universities, and collaborations from laboratories in France and England. Thus target diagnostics have a requirement of providing standalone, self contained operation to accommodate calibration and integration of the diagnostic into control systems outside of the NIF facilities. To accommodate these requirements a centralized controls team was established

to develop a standardized set of reusable modular controllers that can be rapidly incorporated into diagnostics. This flexible hardware and software architecture has proven to be a very effective and efficient means of integrating 36 new diagnostics into NIF in 3 years. It also has proven to provide the flexibility needed to respond to the ever changing requirements of the installed base of diagnostics, while still maintaining software configuration management and quality assurance.

Table I. Target diagnostics commissioned for NIF experiments

NIF Commissioned Target Diagnostics			
Class	Type	# Diag	#Instr
Optical	Full Aperture Backscatter (FABS)	2	18
	Near Backscatter Imager (NBI)	3	23
	Velocity Interferometer (VISAR)	1	10
X-Ray	Soft X-ray power diagnostic (DANTE)	2	42
	Hard X-ray Spectrometer (FFLEX)	1	18
	X-ray Diode (XRD)	3	12
	Gated X-ray Detectors (GXD)	3	9
	X-ray Streak Camera (DISC)	2	9
	High yield Gated X-ray Imager (HGXI)	2	3
	Cmos Camera X-ray Imager (CCXI)	3	9
	Static X-ray Imager (SXI)	2	4
Neutron	Neutron Time-of-Flight (NTOF)	8	57
	Neutron Activation (NAD)	1	3
	Neutron Imaging (NIS)	1	21
	Gama Reaction History (GRH)	1	21
	Electro-Magnetic Pulse (EMP)	1	4
<b>Total</b>		<b>36</b>	<b>263</b>

## 2. Diagnostic Control System (DCS)

### 2.1 Architecture

#### 2.1.1 Diagnostic based architecture

The controls and data acquisition for the suite of diagnostics used for early NIF experiments followed a very traditional, computer controls architecture. Each diagnostic was controlled by a specialized Diagnostic Control System (DCS) computer controller. The various

power supplies, cameras, digitizers/scopes, referred to as instruments used by a diagnostic, were interfaced to a single specialized computer controller. Each controller was a 4U (7 in.) high rack mountable computer with a disk running Windows XP™. A single specialized software application written in Java, and specialized user interface was used to control each target diagnostic.

Even though the DCS diagnostic based architecture worked to support the 5 diagnostics needed during the early NIF campaign of experiments, the overall control system development efficiency, testing, and maintenance costs were high. After the early NIF experiments, we reviewed lessons learned and adopted a modular controls approach to better serve the needs of NIF target diagnostics community in the coming years while improving the performance and reliability. The Goals established for this new approach included:

- Reduced overall hardware and software costs
- Increased efficiency by reusing software
- Improved verification and test case coverage
- Increased development agility for new and modified diagnostics

#### 2.1.2 Instrument-based architecture

An instrument-based Diagnostic Control System (DCS) architecture was developed to achieve these goals. A diagnostic's supporting instruments (i.e., power supplies, cameras, and/or digitizers) are each supported by a dedicated computer controller with generic DCS data driven software that is specialized to that instrument and then customized for use on the diagnostic. Figure 2 illustrates this architecture for the Gated X-ray detector diagnostic (GXD).

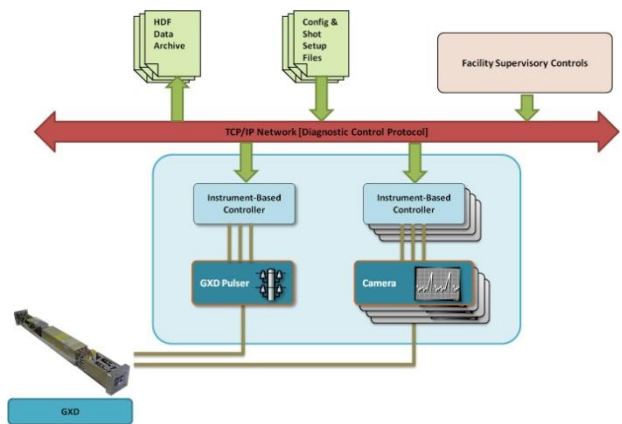


Fig.2 Diagnostic control system architecture as applied to GXD diagnostic

In this example the GXD diagnostic uses one DCS controller with software and interface hardware specific to the camera and a second controller with software and interface specific to the micro channel plate pulser. While the software for the pulser is specific to the GXD, the software for the camera can be reused independently by other diagnostics which use the same type of camera.

The instrument-based hardware and software architecture provides the flexibility and scalability that is needed to control modify the wide variety of NIF diagnostics. Scaling is achieved by using a single controller per instrument. This allows many hundreds of instruments to be added to the control system. The only practical limit is the network and network file system infrastructure. The architecture is also very flexible as it allows for instruments to be added, removed or instrument type changed without requiring software modifications. To modify a diagnostic all that is required is to define the new instrument behavior by updating the instrument configuration files and installing and commission the appropriate instruments hardware and their associated controllers.

## 2.2 Diagnostic controller hardware

We currently have 36 commissioned diagnostics in NIF. The instruments for these diagnostics are controlled by over 260 PC computers. Figure 3 shows the location of these controllers within the NIF facility.

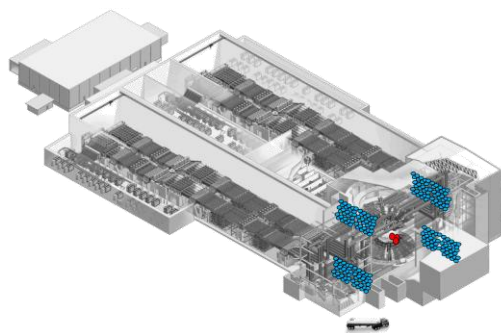


Fig.3 Location of Diagnostic controllers located within the NIF building.

The majority of these controllers, the blue dots on figure 3 are located in the Diagnostic Mezzanines where they are shielded from the target chamber neutrons by a thick concrete wall. These controllers are diskless 1U PC computers running windows XP. They contain 2 PCI slots which allows a specific instrument interface card to be installed to control an instrument when necessary. This allows the same controller hardware to be used for all target diagnostics instruments that are not embedded.

There are three embedded controllers, the red dots on figure 3, which are located in the target chamber and removed for high yield shots to prevent neutron damage. The Gated X-ray Detector (GXD) shown in figure 4 has an embedded controller that is used to concentrate GXD's 50+ control points to allow GXD to reside inside the NIF target chamber while it is under vacuum minimizing the number of required external cables.

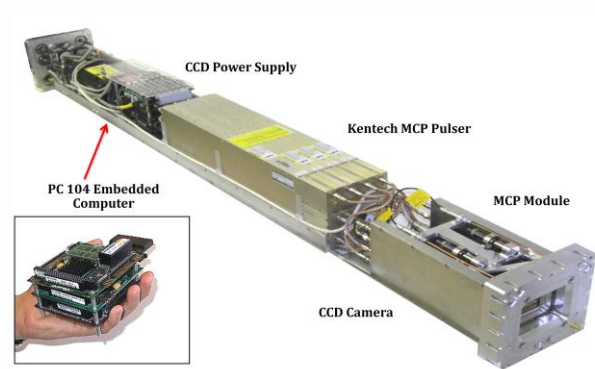


Fig.4 Embedded PC104 controller used in GXD.

This embedded controller is an industrial standard PC104 which is a 4" cube that contains a diskless PC computer running windows XP. This PC104 computer stack is capable of running the same instrument controller software that is used on the rack mount controllers.

## 2.3 Target Diagnostic Software

### 2.3.1 Diagnostic Software framework

The software development of a new instrument controller needs to be done as efficiently as possible so a DCS framework which is an objected-oriented Java-based modular software library was developed. This component library provides all the major functions necessary to create controls software for a specific target diagnostic instrument. Figure 5 illustrates the DCS Framework, which instantiates objects that perform the common functions described below [3].

The XML parser reads and validates the DCS XML configuration file at controller startup. This file defines parameters such as hardware configuration, data-set definitions, and instrument specific commands. Upon request from ICCS, the setup files are parsed and validated using a data schema. The setup files contain controller specific commands that are stored in the Data Manager and executed during defined controller states or during NIF shot countdown ticks.

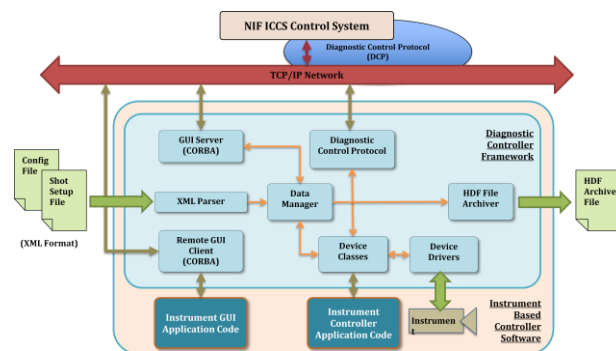


Fig.5 Diagnostic controller software framework.

The Data Manager is the data broker for the controller that acquires, stores, and makes available data defined in

the instrument-specific Java code for the device, GUI and Archiver.

Upon an archive request from ICCS, the Archiver gathers the data stored in Data-sets and creates a structured Hierarchical Data Format (HDF) file at the specified location. The archived data is then processed by the data analysis team.

The GUI Server provides remote access to the controller data using the Data-set Manager. The GUI client creates XML messages and sends them to the GUI Server via CORBA. The GUI Server parses the XML and executes control sequences or makes data available to the GUI client. By default an automatic tabular-form GUI is created based on the available Data-sets. Optionally, a customized GUI application can be written to implement more complex GUI requirements.

The device classes interface between the DCS frameworks and the Java code that provides instrument-specific functionality, determining what data sets are available and what functionality the GUI provides.

The DCP Manager implements the Diagnostic Control Protocol (DCP) for the controller. The DCP protocol is a simple TCP/IP based protocol that provides a loosely coupled standard interface between the diagnostic controllers and a supervisory control system. It accepts state transition commands from the supervisory control system, implements the controller state machine, executes commands defined in the configuration XML files, and sends high-level status and state information back to the supervisory control system as described in the next section.

### **2.3.2 Target Diagnostics supervisory software**

The ICCS target diagnostics supervisory software provides the primary operator interface at the Target Diagnostic console in the control room. The ICCS target diagnostic subsystem software consists of GUI and manager software. The GUI software is written in JAVA and runs on the operator consoles. The manager software is written in Ada and executes on Sun Solaris servers. The manager software is comprised of target diagnostic Front End Processor containing Diagnostic Bridges, supervisory and shot control software. Diagnostic Bridges translate DCP protocol messages from each DCS instrument into ICCS CORBA-distributed objects. The target diagnostic supervisor uses these bridges to provide status and control of each DCS instrument, and groups the set of instruments for the diagnostics they support. The shot supervisor executes macro steps that are defined in a shot model for participating diagnostics on any given shot [2]. The supervisory system allows the independent diagnostic controllers to be coordinated and synchronized in the high level NIF laser shot cycle.

## **3. Conclusions**

Development and testing of DCS controllers is focused on the instrument and validates all required features of the instrument. Developers specialize on instrument types and families where feasible. This has led to increased efficiency and flexibility in development and fielding controls for target diagnostics.

By developing new diagnostics using DCS supported instruments, the cost of bringing diagnostics on-line has been reduced. The modular DCS approach has enabled closer cooperation between diagnostic hardware engineers and the DCS software developers and testers. Similarly, the team has become more responsive as development time for new diagnostics has been reduced through reuse of standardized power supplies, cameras, scopes, and digitizers.

The chosen hardware and software architecture has met the requirements and goals derived from target diagnostic needs as well as from ICCS interface requirements. 36 diagnostics composed of over 260 DCS instruments have been brought online and were utilized in 2009-2011 experimental campaigns. Over the next few years more than 20 new or significantly modified diagnostics will be commissioned in the NIF. To support these new diagnostics, 8 new instrument controllers will need to be developed and tested and over 125 instruments and controllers will be deployed to support the NIF user facility campaign beginning in 2013.

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